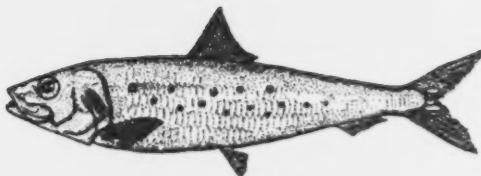




EVALUATION OF PACIFIC SARDINE (*SARDINOPS SAGAX*) STOCK ASSESSMENT AND HARVEST GUIDELINES IN BRITISH COLUMBIA



Source: Fisheries & Oceans Canada

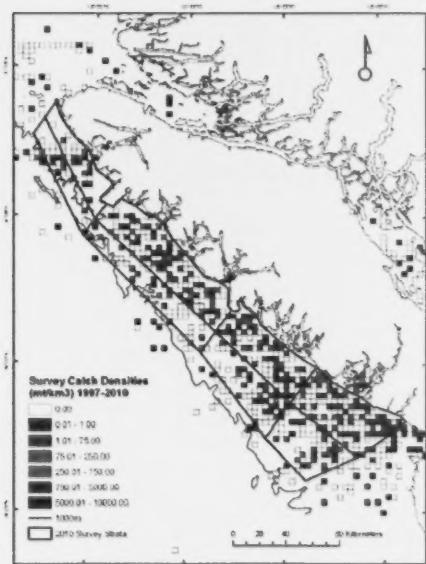


Figure 1: Mean sardine densities for all 1997-2010 sardine survey observations combined, based on 4x4km sized grid cells, and boundaries defining the core WCVI survey region.

Context :

The Pacific sardine (*Sardinops sagax*) is an annual migrant to Canadian waters moving northward from California in the spring to feeding grounds in British Columbia waters and returning south in the fall. The sardine population collapsed to very low levels in the mid-20th century, disappearing altogether from Canadian waters. A coast-wide recovery of the stock began in the 1980s. The Canadian sardine fishery has harvested sardines experimentally since 1995 and commercially every year since they were declared not at risk by COSEWIC in 2002.

The current Canadian harvest rule is based on the U.S. assessment of coastwide adult biomass and the migration rate of sardines into Canadian waters, upon which a harvest rate equivalent to the U.S. rate is established (a 15% harvest rate has been in place since 2002). The Canadian sardine industry has shown interest in developing a harvest policy independent of the U.S. stock assessment, in favour of using the British Columbia seasonal estimate of sardine biomass from summer research trawl survey.

Advice was requested by Fisheries and Aquaculture Management (FAM) to review the feasibility of adopting the alternative trawl survey based rule, to identify potential issues, and to provide advice on sardine seasonal abundance and migration rate in Canadian waters.

This Science Advisory Report has resulted from a Fisheries and Oceans Canada, Canadian Science Advisory Secretariat Pacific Regional Advisory Process. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at <http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm>.

SUMMARY

- Independent surveys conducted by the U.S and British Columbia have reported a significant decrease in sardine biomass since 2006. Comparing biomass estimates of 2006 to that of 2010, the U.S. coastwide biomass has decreased by 57% whereas the WCVI estimate from the trawl survey has decreased by 79%.
- The sardine biomass estimated from the annual summer research surveys has decreased during the past 4 years with the highest estimate in 2006 (381,617 tonnes) and lowest in 2010 (81,964 tonnes). The decrease in biomass has coincided with unusual ocean conditions which may have affected abundance and distribution.
- The incorporation of inshore areas into the current harvest control rule was determined to be an acceptable assumption. Using the U.S. coastwide biomass estimate of 537,173 tonnes and a harvest rate of 15%, the TAC for 2011 is set at 21,917 tonnes based on a migration rate estimate of 27.2%. This TAC amount represents an increase of 4,192 tonnes over using the core survey area biomass results only.
- Understanding the migration timing and extent remains a challenging issue in developing the harvest guideline and further work to investigate the importance of environmental factors, particularly temperature, should be undertaken.

INTRODUCTION

The Pacific sardine, *Sardinops sagax* (Family Clupeidae), is one of 18 species from three genera world-wide. Sardines are found in the waters of every ocean but they are a warm water species whose global distribution is restricted to 60N and 50S latitude. Sardine in the north-east Pacific have been shown to undergo long term fluctuations in abundance. The population in the eastern Pacific disappeared in the late 1940s and did not reappear until the early 1980s. As the population has rebuilt it has expanded its range, migrating extensively into Canadian waters and providing new fishing opportunities. The extent of northward migration varies annually, likely a function of environmental conditions.

Rationale for Assessment

Determining the timing and extent of the sardine migration is challenging but critical to the precautionary management of the resource. The current Canadian harvest rule is based on the U.S. assessment of coastwide adult biomass and the migration rate of sardines into Canadian waters, upon which a harvest rate equivalent to the U.S. rate is established (a 15% harvest rate has been in place since 2002). The objectives of this assessment were 1) to assess the feasibility of adopting the alternative Canadian trawl survey independent of the U.S. assessment, and 2) to provide advice on sardine seasonal abundance and the migration rate into Canadian waters for the management of the 2011 fishery, and 3) to explore the possibility of including additional sardine habitat within the current harvest control rule framework.

Species Biology

The sardine is a schooling pelagic species having a dark blue or green dorsal surface and silvery sides with black spots visible through the scales. Sardines are found in the waters of every ocean and the Pacific sardine is distributed from northern Mexico to southeastern Alaska, although the main centres of concentration range from southern California (northern Baja) to the southern portions of British Columbia.

Pacific sardines are batch spawners. The main spawning grounds are between Point Conception and Ensenada (major spawning ground) as well as off central Baja California. Spawning is thought to be restricted between 13°C to 22°C. It appears that in warm periods, such as during strong El Niño events, environmental conditions may be conducive to sardine spawning in more northern waters (off the Oregon and British Columbia coasts); however, this does not appear to be an annual event.

Small females (13-15 cm) can release close to 30,000 eggs, whereas larger females (>21 cm) can release about 200,000 eggs per spawning season. Each year, beginning early in their second summer, sardines migrate northwards into Canadian waters and travel back south again in the fall. The migrations are complex, with timing and extent of movements affected by population size and oceanographic factors. Specifically, the northward migration appears to be constrained by the 12°C isotherm (Ware 2001).

Currently, in Canadian waters, few fish are younger than age four. Most are 7 years old, representing the 2003 year class which had the largest recruitment to the population during the past decade. Sardines are opportunistic filter feeders. McFarlane et al. (2010) reported that copepods, euphausiids, and diatoms are important prey items for adult sardines off the West Coast of Vancouver Island (WCVI). Sardines are also an important forage item within the California Current ecosystem as prey for a variety of marine fishes, mammals, and seabirds.

ASSESSMENT

Sardine abundance in Canadian waters has been monitored almost annually since 1997 using a trawl survey conducted off the WCVI. Biomass estimates from the trawl survey were compared to the total coastwide abundance from the annual U.S. stock assessment to determine the migration rate into Canadian waters. The trawl survey relies on a series of surface tows conducted throughout the offshore sections of the WCVI. However, in recent years a substantial portion of the total annual sardine landings have come from areas north of Vancouver Island not sampled by the trawl survey. One objective of this assessment was to attempt to account for sardine biomass in areas that have been fished but not surveyed for sardine abundance.

To calculate sardine biomass for the WCVI, annual catch densities from the research trawl survey are applied to the volume of the survey area. The total volume of the WCVI core survey region was determined to be 502.2km³ based on the assumption that sardine inhabit the upper 30m of the water column. It was recognized that the boundaries of the core survey region were conservative as they do not account for sardine presence in areas such as WCVI inlets and Queen Charlotte Sound. In an effort to account for these areas, a cumulative list of Pacific Fishery Management Areas (PFMAs) summarizing commercial catch locations was compiled for the June 1st to August 31st period for four years (2006-2010). It was assumed that this would incorporate areas inhabited by sardines immediately before, during, and after the trawl sampling in the core survey region. A total of 46 sub-areas were found to have some fishing activity during this time frame. The combined spatial volume in these areas was estimated to be 103.9 km³. Abundance and migration calculations were conducted for the core area and for these additional inshore areas (IA) in developing available harvest guidelines.

Biomass Trends

The annual assessment of sardine abundance is conducted by U.S. and Mexican scientists using an age structured model. The model uses both fishery-dependent and fishery-independent data to obtain annual estimates of sardine abundance. The most recent assessment report (see Figure 2 below) indicates that coastwide sardine biomass increased rapidly through the 1980s and 1990s, peaking at approximately 1,570,000 tonnes in 2000 (Hill et al. 2010). With a coastwide biomass of 1,248,410 tonnes in 2006, the population has been in decline for the past four years. The 2010 biomass estimate is 537,173 tonnes. Low recruitment from 2006 to 2009 is the key factor in the decline in sardine biomass.

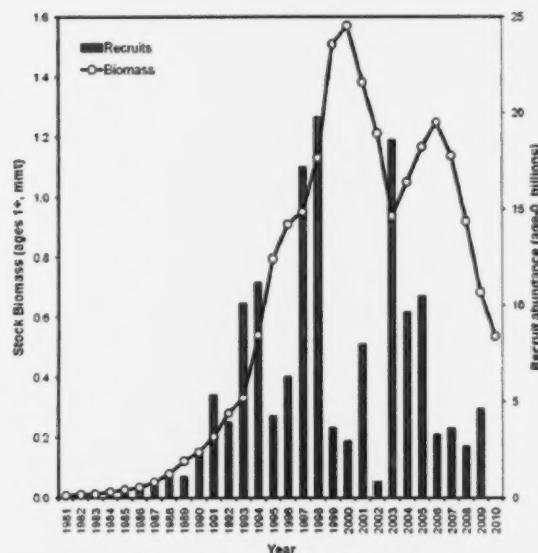


Figure 2: Abundance trends for age 1 recruits (by year class) and adult coastwide biomass. Information from Hill et al. 2010 (Fig.40)

The Canadian research trawl survey which is conducted independently of the U.S assessment has observed the same downward trend since 2006. Mean sardine catch density in 2006 was 759.9 t/km³ and considerably lower in 2010 at 163.2 t/km³. Biomass estimates for the core survey region declined from 391,617 tonnes in 2006 to 81,964 tonnes in 2010 (Figure 3, Table 1).

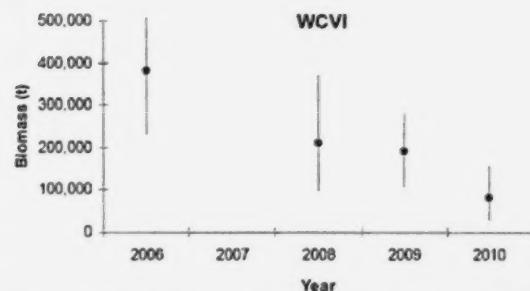


Figure 3: West coast of Vancouver Island mean biomass estimates for core survey region (and 95% confidence intervals) for 2006 to 2010. The survey was not conducted in 2007.

Table 1: Estimates of sardine biomass (with lower and upper confidence intervals) in the WCVI core survey region, WCVI and inshore areas combined, and coastwide (Mexico, U.S. and Canada) biomass and corresponding estimates of seasonal migration rate for 2006-2010.

YEAR	2006	2007	2008	2009	2010	2008-2010
BIOMASS (tonnes)						
WCVI						Mean
Mean	381,617		210,924	189,977	81,964	180,955
95% LL	231,816		98,682	110,589	28,927	79,399
95% UL	555,232		369,820	280,127	155,541	268,496
WCVI + IA						
Mean	460,569		254,562	229,282	98,922	194,255
95% LL	279,776		119,099	133,469	34,911	95,826
95% UL	670,104		446,332	338,083	187,721	324,045
Coastwide (S1)						
Mean	1,248,410	1,137,980	919,328	683,575	537,173	713,359
95% LL	743,970	686,134	538,281	370,106	257,993	388,793
95% UL	1,752,850	1,589,826	1,300,375	997,044	816,353	1,037,924
MIGRATION RATE						
WCVI	30.6%		22.9%	27.8%	15.3%	22.0%
WCVI + IA	36.9%		27.7%	33.5%	18.4%	27.2%

There has been a variable but decreasing migration rate from 2006 to 2010 (Table 1). The result has been a variable but slightly increasing TAC and harvest in B.C., but a decline in the U.S. as the stock biomass has decreased (Table 2).

Table 2: Observed annual sardine harvests in B.C. and in all U.S states (Washington, Oregon and California) over 2006-2010. Also shown are the applied total allowable catches (by country) and current biomass estimates by region(s) within B.C. (core WCVI survey region plus inshore areas (IA) and coastwide.

Year	Harvest		TAC		Biomass	
	B.C.	U.S.	B.C.	U.S.	WCVI+ IA	Coastwide
2006	1,558	90,776	13,500	118,937	460,569	1,248,410
2007	1,524	127,695	19,800	152,564	*396,726	1,137,980
2008	10,435	87,175	12,491	89,093	254,562	919,328
2009	15,334	67,084	18,196	66,932	229,282	683,575
2010	20,000	63,301	23,166	72,039	98,922	537,173

*2007 biomass estimate (and mean density) were interpolated. 2010 harvests are in-season estimates (as of ~December 1, 2010).

The estimate of the actual harvest rates for B.C. relative to the coastwide biomass has increased from 0.1% in 2006 to 3.7% in 2010 (Table 3). However, based on the estimated biomass within B.C. using the trawl survey estimate, the harvest rate in 2010 for either the core WCVI region or the core + inshore areas was 24.4 or 20.2%, respectively. Combining the U.S. and B.C. harvests results in an estimated harvest rate of 15.5% relative to the coastwide abundance estimate, although neither jurisdiction reached its target TAC.

Table 3: Estimates of realized harvest rates for WCVI core region, WCVI + Inshore Areas (IA), British Columbia, Washington + Oregon, and U.S. based on current biomass and coastwide estimates. Also shown is the realized proportion of each country's total allowable catch that was harvested.

Year	WCVI B.C.	WCVI+ IA B.C.	B.C. Coastwide	WA+OR Coastwide	U.S. Coastwide	U.S.+B.C. Coastwide	B.C. TAC	U.S. TAC
2006	0.4%	0.3%	0.1%	3.20%	7.3%	7.4%	11.5%	76.3%
2007	0.5%	0.4%	0.1%	4.10%	11.2%	11.4%	7.7%	83.7%
2008	4.9%	4.1%	1.1%	3.20%	9.5%	10.6%	83.5%	97.8%
2009	8.1%	6.7%	2.2%	4.30%	9.8%	12.1%	84.3%	100.2%
2010	24.4%	20.2%	3.7%	6.00%	11.8%	15.5%	86.3%	87.9%

2010 harvests are in-season estimates (as of ~December 1, 2010).

Harvest Control Rules

The B.C. sardine harvest control rule (in effect since 2009) is modeled on the U.S. stock assessment process and uses the product of the three terms below to provide advice on harvest ceilings for the management of sardines:

- (1) U.S. estimate of total coastwide (Mexico, U.S. and Canada) adult biomass (age-1 and older) for semester 1 (July 1-Dec 31) of the most recent year (537,173 tonnes in 2010).
- (2) A 3 year running average migration rate from the most recent trawl surveys.
- (3) The U.S. harvest rate, which has been fixed at 15% since 1990.

Four harvest control rule options were reviewed at the Regional Advisory meeting. The first two options use the current harvest control rule framework.

1. a) A provisional TAC of 17,725 tonnes, based on the 2010 estimate of coastwide biomass (537,173 tonnes), an updated migration rate based on estimates for the WCVI core survey region alone (22.0%), and a 15% harvest rate.
- b) A provisional TAC of 21,917 tonnes, based on the 2010 estimate of coastwide biomass (537,173 tonnes), an updated migration rate based on estimates for the WCVI core survey region and inshore areas combined (27.7%), and a 15% harvest rate.

The second two options explored an alternative harvest control rule which determines a TAC independent of the U.S. assessment.

2. a) A provisional TAC of 12,295 tonnes, based on the 2010 WCVI core survey region biomass estimate (81,964 tonnes) and a 15% harvest rate.
- b) A provisional TAC of 14,838 tonnes, based on the 2010 WCVI core survey region and inshore areas combined biomass estimate (98,922 tonnes), and a 15% harvest rate.

It was concluded that option 1 b) was the most appropriate recommendation at this time. Extrapolation of the survey density to inshore areas is a reasonable assumption based on reports of high densities observed by commercial harvesters in those areas. Since inshore areas are preferred habitat for sardine, it is likely that the inshore regions have a higher density than the WCVI core region. Therefore, the incorporation of inshore areas into the harvest control rule is still considered to be conservative. Future research is necessary to investigate alternative approaches for surveying other areas of the B.C. coast and the applicability of alternative harvest control rules.

Sources of Uncertainty

As with any stock assessment process, uncertainties and assumptions affect estimates of total abundance. Within B.C., the major assumptions around the accuracy of the trawl survey biomass relate to the timing of the survey in relation to the peak summer abundance of sardine in B.C. waters, and that fish are constrained to the upper 30 m and are 100% catchable by the gear. Similarly, there are uncertainties in the coastwide biomass estimate from the U.S. assessment which relate to the egg deposition estimate and to the aerial survey estimate, both of which are important factors in fitting the model. In addition, there appear to be some issues around accuracy of age determination, as older fish from the 2003 year-class are not appearing in the expected abundance within survey or fishery samples.

In an attempt to account for sardine abundance in inlets on the WCVI and areas north of Vancouver Island, where a substantial portion of the annual catch has been taken, it is assumed that the density is similar to that observed during the trawl survey, but this has not

been tested. Nevertheless, there are anecdotal reports of significant sardine abundance within these areas.

CONCLUSIONS AND ADVICE

Harvest Advice

Different harvest options were reviewed and the option recommended incorporates the estimated biomass in the inshore areas into the current harvest control rule. Under the current management framework, the resulting TAC for 2011 would be 21,917 tonnes; an increase of 4,192 tonnes above the TAC using only the core survey area biomass. The current analysis did not include an evaluation of the rationale used by the U.S. to determine the harvest rate. This is an ongoing area of research by U.S. scientists and alternate harvest options are anticipated in future assessments.

Stock Status

The coastwide (Canada, U.S., and Mexico) sardine biomass has declined from the recent peak in 2006, which was largely a function of the very strong 2003 year-class. Based on the U.S. assessment, the 2010 coastwide biomass estimate was 537,173 tonnes. Sardine recruitment is highly variable and driven primarily by environmental factors. Without good recruitment, the sardine biomass is anticipated to decline further. Concern was expressed for the comparative loss of potential recruits due to removal of younger (smaller) fish by a U.S. fishery and older (larger fish) harvested by the Canadian fishery.

Biomass Estimation Methodology & Results

The revised methodology, which includes inshore areas in the estimation of biomass in B.C., is recommended, since the original core survey area does not include sardines which are known to be present in inshore areas of the B.C. coast. Significant landings have been reported in these inshore areas over the last four years. Consequently, the total area considered in the accepted harvest control rule increases estimated biomass by about 21% in comparison to the previously accepted methodology.

Ecological considerations

Sardines are an important forage species and further work on their role within the marine ecosystem is recommended to assess the impacts of a declining coastwide population on both marine fish, mammal, and bird populations.

Future Research and Analysis

A range of recommendations were suggested to improve the assessment of sardine biomass in B.C. waters including:

- Incorporation of environmental indicators and additional survey methodologies (e.g. aerial coverage, satellite imagery) should be explored to complement the trawl survey in future assessments;
- Further exploration of the trawl survey data to evaluate the effect of climate and environmental conditions on sardine migration, and its utility as a predictive tool. Calibrate past surveys if ocean conditions are found to have an effect;

- Comparison of transect and randomized grids using post stratification to assess variability in abundance estimates;
- Validation of the assumptions about sardine distribution and abundance in inshore areas and core area as well as catchability for trawl surveys;
- Addressing the apparent uncertainty of age determination of older fish (4+) due to the importance of this information in making accurate stock assessments; and,
- Industry, academia, and tri-national government agency collaborations are encouraged for ongoing studies of sardines and their role in the ecosystem.

OTHER CONSIDERATIONS

In the winter of 2011, the U.S. will undertake a major review of its sardine survey methodologies. Modifications to the biomass index survey data will impact the U.S. sardine assessment and may affect the Canadian harvest guidelines, since the current framework is based on the U.S. coastwide biomass estimate.

The U.S. has planned two coastwide surveys in 2012 in April and July. In addition to sardine data, biology and distribution of other species (anchovy, juvenile salmon, and hake) will be collected. Canada's participation in the summer 2012 study is encouraged and welcomed. Canadian involvement in this project offers an opportunity to study and compare independent trawl observations, acoustics, ichthyoplankton, and aerial survey work.

SOURCES OF INFORMATION

This Science Advisory Report has resulted from a Fisheries and Oceans Canada, Canadian Science Advisory Secretariat Pacific Regional Advisory Meeting of January 18, 2011 on Assessment of Pacific Sardine. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at <http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm>.

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FOR MORE INFORMATION

Contact: Jake Schweigert
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, B.C.
V9T 6N7
Tel: 250-756-7203
Fax: 250-756-7138
E-Mail: Jake.Schweigert@dfo-mpo.gc.ca

Contact: Linnea Flostrand
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, B.C.
V9T 6N7
Tel: 250-756-7187
Fax: 250-756-7138
E-Mail: Linnea.Flostrand@dfo-mpo.gc.ca

This report is available from the:

Centre for Science Advice (CSA)
Pacific Region
Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

Telephone: 250-756-7208

Fax: 250-756-7209

E-Mail: CSAP@dfo-mpo.gc.ca

Internet address: www.dfo-mpo.gc.ca/csas-sccs

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